A Precision Measurement of Nuclear Muon Capture on ^{3}He

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In an experiment performed at PSI Switzerland our collaboration has measured the muon capture rate in the reaction $\mu^- + {}^3\mathrm{He} \rightarrow \nu_\mu + {}^3\mathrm{H}$ $(1.9\,\mathrm{MeV}, \mathrm{BR} \approx 0.33\%)$ with unprecedented accuracy. Our results allow new tests of PCAC and chiral perturbation theory [1 2 3].

At first glance it might seem that one could more easily compare the simpler system $\mu^- + \mathrm{p} \rightarrow \nu_\mu + \mathrm{n}$ to the more accurate theoretical predictions associated with it. However, the experiment is difficult to carry out with precision as both reaction products are neutral and also the initial state of the muon is uncertain due to the formation of pμp mesonic molecules. The $\mu\,{}^3$He system turns out to be much more accessible; the muon is quickly bound in the 1s state and there is a charged particle (triton) which can be detected with extreme efficiency.

We used a high-pressure ionization chamber as an active target to count both the tritons and the incoming muons with 100% efficiency for the time region of our measurement. The monoenergetic tritons form a peak at 1.9MeV in figure 1. The only remaining background is from the "breakup" reactions $\mu^- + {}^3\mathrm{He} \rightarrow \nu_\mu + \mathrm{d} + \mathrm{n}$ and $\mu^- + {}^3\mathrm{He} \rightarrow \nu_\mu + \mathrm{p} + \mathrm{n} + \mathrm{n}$, which occur at rates of 27% and 15% relative to the main reaction.

The theory of the A=3 system is well known from the related system ${}^3\mathrm{H} \rightarrow {}^3\mathrm{He} + \overline{\nu}_e + e^-$. Recent improved calculations [4] predicted a capture rate $\lambda_{\mathrm{stat}} = 1502 \pm 27\,\mathrm{s}^{-1}$ (as compared with 1305 s^{-1} for no meson exchange currents). Our final result $\lambda_{\mathrm{stat}} = 1496 \pm 3 \pm 3\,\mathrm{s}^{-1}$ confirms this calculation and even calls for more precise predictions (stat refers to the statistical population of the muonic hyperfine levels).

Our result confirms PCAC for the nuclear pseudoscalar ^{3}H-^{3}He form factor $F_P(q_0^2)$ to within 15%:

$$\frac{F_P(q_0^2)}{F_P^{\mathrm{PCAC}}(q_0^2)} = 1.005 \pm 0.145\,, \qquad (1)$$

where most of the error now resides in the theoretical calculations (q_0^2 is the momentum relevant to the capture reaction).

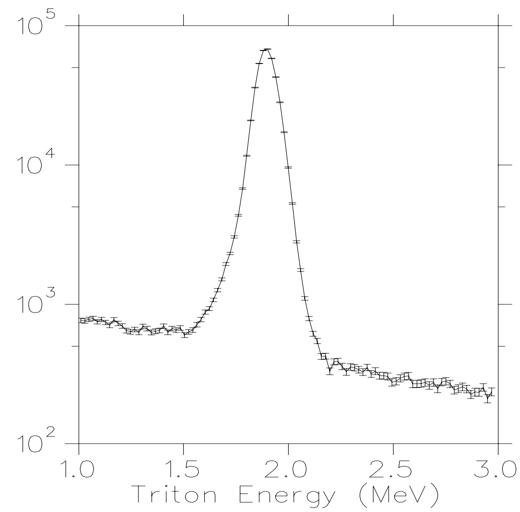

Figure 1: Energy distribution of the tritons from $\mu\,{}^3$He capture. The background is from the associated breakup reactions with energies from 0 to 50 MeV.

Footnotes and References

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